PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

United States Patent and Trademark Office
(Box PCT)
Crystal Plaza 2
Washington, DC 20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing: 18 June 1998 (18.06.98)	
International application No.: PCT/EP97/05417	Applicant's or agent's file reference: NEP/CASE D
International filing date: 26 September 1997 (26.09.97)	Priority date: 12 December 1996 (12.12.96)
Applicant: ALBERTINI, Carlo et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International preliminary Examining Authority on:

02 May 1998 (02.05.98)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was
[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer: J. Zahra Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

H.N. & W.S. SKERRETT
Charles House
148/9 Great Charles Street
Birmingham B3 3HT
GRANDE BRETAGNE

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing *(day/month/year)*	08.03.99
Applicant's or agent's file reference NEP/CASE D	**IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/EP97/05417	26/09/1997	12/12/1996

Applicant
EUROPEAN COMMUNITY et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

   The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

   Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

   For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. (+49-89) 2399-0 Tx: 523656 epmu d Fax: (+49-89) 2399-4465	De Caevel, J-M Tel.(+49-89) 2399-2557

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference NEP/CASE D	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/EP97/05417	International filing date *(day/month/year)* 26/09/1997	Priority date *(day/month/year)* 12/12/1996
International Patent Classification (IPC) or national classification and IPC G01V1/145		
Applicant EUROPEAN COMMUNITY et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 9 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand 02/05/1998	Date of completion of this report 08.03.99
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. (+49-89) 2399-0 Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Authorized officer Dighaye, J-L Telephone No. (+49-89) 2399 2823

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. This report has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

Description, pages:

5-7,9,10	as originally filed			
1-4,4a,8	as received on	04/02/1999	with letter of	01/02/1999

Claims, No.:

1-16	as received on	04/02/1999	with letter of	01/02/1999

Drawings, sheets:

1/2,2/2	as originally filed

2. The amendments have resulted in the cancellation of:

☐ the description, pages:
☐ the claims, Nos.:
☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-16
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-16
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-16
	No:	Claims	

2. Citations and explanations

see separate sheet

To Section V

1. The preamble of claim 1 is based on D1 = EP-A- 7 740. The characterising portion of the claim recites that "the elastic energy accumulator member has a number of sections of different diameters". This feature is not disclosed in D1 since the energy accumulator of D1 is a steel cable 1 (p. 3, l. 11). Nothing indicates that the cable of D1 would be an unusual cable having several sections. Hence claim 1 is novel over D1.

   In addition, claim 1 appears to be inventive over D1. The problem to be solved is the generation of complex wave forms part in tension and part in compression as required for the true simulation of a seismic wave. Such wave forms cannot be generated using the energy accumulator (i. e. the cable) of D1 alone because the cable of D1 can be subjected to tension not to compression (since this would cause destructive buckling). A compression wave can be obtained only by using an accessory such as a bunker (D1, p. 3, l. 17) or inversion cage. In any case it is not possible to generate complex wave form due to the substantially constant cross-section of the cable. By contrast, the energy accumulator of present claim 1 is much stiffer than that of D1 since the section thereof having the smallest diameter must be at least as large as the section of the cable of D1 (otherwise the accumulator would rupture upon tensioning), and the other sections are by definition even larger. As a consequence, not only the accumulator can be compressed but also, when the accumulator is released, complex waves are generated by virtue of wave reflections according to the changes in cross-sections, see also the description pp. 6-7.

   The other documents cited in the international search report are not relevant:
   - GB-A-2 211 611 discloses an impacting seismic source with a bar 3 which does not have several cross-sections, see Fig. 1;
   - FR-A-2 229 967 and EP-A- 410 370 are directed to dynamic tests in tension and torsion, respectively;
   - The vibrator system of WO-A-81/00459 does not hint to the embodiment of claim 1, see Fig. 2;
   - The IEEE article concerns piezoelectric sensors; and
   - The evaluation device of JP-A-07 195300 is completely different from the claimed one, see the figure in the abstract (publication number 09 043 093).

2. Claims 2-15 are dependent apparatus claims and appear novel and inventive in combination with claim 1.

3. Independent method claim 16 comprises the inventive feature of claim 1, see p. 13, ll. 35-36 of the application: "a number of sections of different diameters".

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference NEP/CASE D	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/EP 97/05417	International filing date *(day/month/year)* 26/09/1997	(Earliest) Priority Date *(day/month/year)* 12/12/1996
Applicant EUROPEAN COMMUNITY et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. [ ] **Certain claims were found unsearchable** (see Box I).

2. [ ] **Unity of invention is lacking** (see Box II).

3. [ ] The international application contains disclosure of a **nucleotide and/or amino acid sequence listing** and the international search was carried out on the basis of the sequence listing
   - [ ] filed with the international application.
   - [ ] furnished by the applicant separately from the international application,
     - [ ] but not accompanied by a statement to the effect that it did not include matter going beyond the disclosure in the international application as filed.
   - [ ] Transcribed by this Authority

4. With regard to the **title**,
   - [X] the text is approved as submitted by the applicant
   - [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,
   - [X] the text is approved as submitted by the applicant
   - [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this International Search Report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is:

   Figure No. 1
   - [X] as suggested by the applicant.
   - [ ] because the applicant failed to suggest a figure.
   - [ ] because this figure better characterizes the invention.
   - [ ] None of the figures.

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PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

PCT

NOTIFICATION OF RECEIPT OF SEARCH COPY

(PCT Rule 25.1)

To:
H.N. & W.S. SKERRETT
Charles House
148/9 Great Charles Street
Birmingham B3 3HT
UNITED KINGDOM

Date of mailing *(day/month/year)*	16/12/1997
Applicant's or agent's file reference: NEP/CASE D	IMPORTANT NOTIFICATION

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/EP 97/05417	26/09/1997	12/12/1996

Applicant

EUROPEAN COMMUNITY et al.

1. **Where the International Searching Authority and the Receiving Office are not the same office:**

   The applicant is hereby notified that the search copy of the international application was received by this International Searching Authority on the date indicated below.

   Where the International Searching Authority and the Receiving Office are the same office:

   The applicant is hereby notified that the search copy of the international application was received on the date indicated below.

   01/12/1997 *(date of receipt).*

2. ☐ The search copy was accompanied by a diskette containing nucleotide and/or amino acid sequence listings.

3. **Time limit for establishment of International Search Report**

   The applicant is informed that the time limit for establishing the International Search Report is 3 months from the date of receipt indicated above or 9 months from the priority date, whichever time limit expires later

4. A copy of this notification has been sent to the International Bureau and, where the first sentence of paragraph 1 applies, to the Receiving Office.

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	ISA/EP

RECEIVED 22 DEC 1997

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PATENT COOPERATION TREATY

REC'D 10 MAR 1999
WIPO PCT

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference NEP/CASE D	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/EP97/05417	International filing date *(day/month/year)* 26/09/1997	Priority date *(day/month/year)* 12/12/1996
International Patent Classification (IPC) or national classification and IPC G01V1/145		
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   II ☐ Priority
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   VII ☐ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
02/05/1998	08.03.99
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. (+49-89) 2399-0 Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Authorized officer Dighaye, J-L Telephone No. (+49-89) 2399 2823

I. Basis of the report

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Description, pages:

5-7,9,10	as originally filed			
1-4,4a,8	as received on	04/02/1999	with letter of	01/02/1999

Claims, No.:

1-16	as received on	04/02/1999	with letter of	01/02/1999

Drawings, sheets:

1/2,2/2	as originally filed

2. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-16
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-16
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-16
	No:	Claims	

2. Citations and explanations

see separate sheet

To Section V

1. The preamble of claim 1 is based on D1 = EP-A- 7 740. The characterising portion of the claim recites that "the elastic energy accumulator member has a number of sections of different diameters". This feature is not disclosed in D1 since the energy accumulator of D1 is a steel cable 1 (p. 3, l. 11). Nothing indicates that the cable of D1 would be an unusual cable having several sections. Hence claim 1 is novel over D1.

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   The other documents cited in the international search report are not relevant:
   - GB-A-2 211 611 discloses an impacting seismic source with a bar 3 which does not have several cross-sections, see Fig. 1;
   - FR-A-2 229 967 and EP-A- 410 370 are directed to dynamic tests in tension and torsion, respectively;
   - The vibrator system of WO-A-81/00459 does not hint to the embodiment of claim 1, see Fig. 2;
   - The IEEE article concerns piezoelectric sensors; and
   - The evaluation device of JP-A-07 195300 is completely different from the claimed one, see the figure in the abstract (publication number 09 043 093).

2. Claims 2-15 are dependent apparatus claims and appear novel and inventive in combination with claim 1.

3. Independent method claim 16 comprises the inventive feature of claim 1, see p. 13, ll. 35-36 of the application: "a number of sections of different diameters".

M.04.02.99

SEISMIC WAVE SIMULATION APPARATUS

This invention relates to seismic wave simulation apparatus more particularly but not exclusively for simulating earthquake phenomena occurring in soil and in a foundation embedded in the soil, which foundation may be for example, part of a building.

Conventionally, simulation of a seismic wave or earthquake in a structure or building is done by means of a pseudo-dynamic test (reaction wall) or by the "shaking" table. In order to simulate seismic waves or earthquakes occurring in soil, explosives are used which tend to be inconvenient since the explosives do not generate waves of known energy content and shape and duration having characteristics of earthquakes. Thus, using such methods to simulate seismic waves or earthquakes does not allow wave propagation laws and effects to be properly established through seismic wave simulation in soil or other structures.

EP-A-7740 discloses an apparatus for performing dynamic tests on large structures which comprises an energy accumulator in the form of a loading cable for applying a force to a test piece, a hydraulic jack for tensioning the cable, a structure for anchoring the cable, a stopping and releasing device operable to secure the cable before a test and, after tensioning of the cable, to release the cable so that it propagates a wave to the test piece, a recoil shock-absorber and a device for limiting lateral oscillations of the cable.

This apparatus is, however, not suitable for simulating seismic waves because the cable is only capable of generating a tension wave of constant amplitude which is not representative of a seismic wave because seismic waves have complex wave forms with a changing amplitude.

It is an object of the present invention to provide

an apparatus which is capable of simulating complex seismic waves.

According to the present invention there is provided a seismic wave simulation apparatus for generating a simulated seismic wave in a geological specimen, which comprises an elastic energy accumulator comprising a member arranged, in use, to act on the geological test specimen and supported to resist movement in a direction away from the specimen when the elastic energy accumulator is preloaded in said direction by actuator means, the arrangement being such that, in use, the preload force can be quelled suddenly, for example by triggering an explosive bolt, so that the member is released into impact or energy transfer with the geological specimen thereby transmitting a seismic wave to the geological specimen, characterised in that the elastic energy accumulator member has a number of sections of different diameters.

By providing the energy accumulator member with sections of different diameters the member is so shaped as to simulate a seismic wave of known characteristics in order that wave propagation laws and effects can be properly established.

Preferably the elastic energy accumulator member has a number of co-axial cylindrical sections of different diameters of which the section at the end of the member remote from the actuator means constitutes an impactor which, in use, is held adjacent the geological specimen under test so as to impact the specimen on release of the member.

In one embodiment of the present invention, the elastic energy accumulator includes seven cylindrical sections of different diameter. Preferably, one of those sections nearest the actuator means has the smallest diameter of the sections and, where an explosive bolt is

provided as aforementioned, to release the impact energy said explosive bolt is, preferably, provided in this section and preferably is disposed diametrically of said section. Said smallest diameter section may adjoin a large diameter section which is connected to two further sections stepped down in diameter and connected in turn to a smaller diameter section which is larger than said smallest section adjacent the actuator means. This smaller diameter section may be connected to two larger sections which are stepped up in diameter, the last of these sections constituting the impactor to be located adjacent to the geological specimen in use. The length of the elastic energy accumulator (comprised of said seven sections) and the actuator means may be in the order of 500 metres.

The accumulator member may be supported to resist movement in a direction away from the geological specimen under test by said last-mentioned section. A blocking system or fixed support may be provided at the rear of said last-mentioned section surrounding the penultimate section, thereby resisting or preventing movement of the accumulator member in said direction on the application of the preload force.

Usually, the apparatus will include transducers arranged to measure, in use, the mechanical behaviour across the section of the geological specimen through which a seismic wave is being transmitted.

Preferably, the transducers are in the form of bars or elongate members arranged in a direction parallel to the direction of propagation of the seismic wave. Seismic sensors may also be included extending at an angle or transversely of the direction of propagation of the wave.

Preferably, in order to obtain measurements regarding local displacements of the soil in the geological specimen,

said apparatus may include a thin metallic or conductive sheet to be fixed to the surface of the geological specimen (for example by cement) and connected to measuring instrumentation such as a Wheatstone bridge, for example, in order to obtain superficial strain measurement. In carrying out the test a building foundation or the like may be embedded in the geological specimen in order to investigate the interaction between the soil and foundation on the application of a simulated seismic wave.

The measuring instrumentation may include accelerometers.

Further according to the present invention there is provided a method of inducing or generating a simulated seismic wave in a test specimen, for example a geological specimen, said method including providing an elastic energy accumulator comprising a member which is arranged to act on the specimen so as to deliver a seismic wave to the specimen, supporting the elastic energy accumulator to resist movement in a direction away from the specimen and preloading the elastic energy accumulator in said direction, suddenly quelling the preload force, for example by triggering an explosive bolt in the elastic energy accumulator, thereby releasing the elastic energy accumulator into impact or energy transfer with said specimen thereby transmitting a simulated seismic wave to the specimen, collecting data from the specimen and analysing said data, characterised in that the energy accumulator member is so shaped by providing it with a number of sections of different diameters that it delivers a seismic wave of known amplitude and duration.

Further advantageous apparatus and method features of the present invention will be evident from the following description and drawings.

An embodiment of seismic wave simulation apparatus

for generating a seismic wave in a geological specimen will now be described, by way of example only, with reference to the accompanying simplified diagrammatic drawings in which:

FIGURE 1 shows the seismic wave simulation apparatus adjacent a geological specimen having the foundation of a building embedded therein;

FIGURE 2 shows a simple cylindrical bar pre-loaded to yield a virtually rectangular stress wave, and

FIGURE 3 shows cylindrical bars of two different sections arranged to yield a different stress wave pattern.

FIGURE 1 of the drawings shows schematically seismic wave simulation apparatus 1 positioned to the left of a geological specimen 2 in which is embedded the foundation 3 of a building (not shown). The seismic wave simulation apparatus has an elastic energy accumulator 4 comprising an impactor member which can be preloaded in tension in a direction away from the geological specimen 2 (i.e. in a direction reverse to arrow A) by means of a hydraulic actuator 5. The apparatus 1 includes a blocking or support system which effectively fixes the right hand end of the

we obtain a wave which decreases in function of time.

The amplitude and the shape of the wave generated can be found knowing the impedance and also the length of the bars to obtain the transit time. Using the above formula in a numerical programme it is possible to know the shape of the wave which could be generated in function of the geometry of the energy accumulator.

The geological specimen 2 may be a soil rocks specimen and, in order to measure the mechanical behaviour across the section of the geological specimen, transducer bars 8 are provided in the specimen as shown in FIGURE 1. The transducer bars 8 are instrumented with strain gauges and measurements taken in a generally known manner. Additionally, in order to obtain measurements regarding local displacements of the soil in the geological specimen 2 an electrified metallic thin sheet 9 is fixed firmly to the surface of the soil by a cement and connected up to a measuring instrumentation such as a Wheatstone bridge, in the case of resistance strain gauges, in order to obtain superficial strain measurement.

Thus, in the present instance, a simulated seismic wave can be transmitted through the geological specimen 2 and through a building foundation 3, so interaction between the soil and the foundation can be studied and evaluated.

Any other measuring instrumentation may be provided such as the accelerometers 10 and embedded seismic sensor bar 11.

It is believed the seismic wave simulation apparatus 1 can be used to provide a deterministic approach to monitoring and predicting:

(a) earthquakes,
(b) large ground displacements of natural and artificial

CLAIMS

1. Seismic wave simulation apparatus for generating a simulated seismic wave in a geological specimen, which comprises an elastic energy accumulator (4) comprising a member arranged, in use, to act on the geological test specimen and supported to resist movement in a direction away from the specimen when the elastic energy accumulator is preloaded in said direction by actuator means (5), the arrangement being such that, in use, the preload force can be quelled suddenly, for example by triggering an explosive bolt (6), so that the member is released into impact or energy transfer with the geological specimen thereby transmitting a seismic wave to the geological specimen, characterised in that the elastic energy accumulator member (4) has a number of sections of different diameters (4a-g).

2. Apparatus as claimed in Claim 1 in which the elastic energy accumulator member (4) has a number of co-axial cylindrical sections of different diameters (4a-g) of which the section (4g) at the end of the member remote from the actuator means (5) constitutes an impactor which, in use, is held adjacent the geological specimen under test so as to impact the specimen on release of the member.

3. Apparatus as claimed in Claim 2 having a section (4a) nearest the actuator means which is the smallest diameter of the sections.

4. Apparatus as claimed in Claim 3 including an explosive bolt (6) disposed diametrically of said smallest diameter section (4a).

5. Apparatus as claimed in Claim 3 or Claim 4 in which said smallest diameter section (4a) adjoins a large diameter section (4b) which is connected to two further sections (4c,4d) stepped down in diameter and connected in turn to a smaller diameter section (4e) which is larger

than said smallest diameter section (4a) adjacent the actuator means (5).

6. Apparatus as claimed in Claim 5 in which said smaller diameter section (4e) is connected to two larger sections (4f,4g) which are stepped up in diameter, the last of these sections (4g) constituting the impactor to be located adjacent to the geological specimen in use.

7. Apparatus as claimed in Claim 6 in which the accumulator member (4) is supported to resist movement in a direction away from the geological specimen under test, by said last-mentioned section (4g).

8. Apparatus as claimed in Claim 7 in which a blocking system or fixed support is provided at the rear of said last-mentioned section (4g) surrounding the penultimate section (4f), thereby resisting or preventing movement of the accumulator member (4) in said direction on the application of the preload force.

9. Apparatus as claimed in Claim 1 in which the elastic energy accumulator (4) includes seven cylindrical sections of different diameters (4a-g).

10. Apparatus as claimed in any one of the preceding claims in which the combined length of the elastic energy accumulator (4) and the actuator means (5) is of the order of 500 metres.

11. Apparatus as claimed in any one of the preceding claims having transducers (8) arranged to measure, in use, the mechanical behaviour across the section of the geological specimen through which a seismic wave is being transmitted.

12. Apparatus as claimed in Claim 11 in which the transducers (8) are in the form of bars or elongate members

arranged in a direction parallel to the direction of propagation of the seismic wave.

13. Apparatus as claimed in any one of the preceding claims in which seismic sensors (11) are included extending at an angle or transversely of the direction of propagation of the wave.

14. Apparatus as claimed in any one of the preceding claims including a thin metallic or conductive sheet (9) to be fixed to the surface of the geological specimen (for example by cement) and connected to measuring instrumentation such as a Wheatstone bridge, for example, in order to obtain superficial strain measurement.

15. Apparatus as claimed in any one of the preceding claims in which the measuring instrumentation includes accelerometers (10).

16. A method of inducing or generating a simulated seismic wave in a test specimen, for example a geological specimen, said method including providing an elastic energy accumulator (4) comprising a member which is arranged to act on the specimen so as to deliver a seismic wave to the specimen, supporting the elastic energy accumulator to resist movement in a direction away from the specimen and preloading the elastic energy accumulator in said direction, suddenly quelling the preload force, for example by triggering an explosive bolt (6) in the elastic energy accumulator, thereby releasing the elastic energy accumulator into impact or energy transfer with said specimen thereby transmitting a simulated seismic wave to the specimen, collecting data from the specimen and analysing said data, characterised in that the energy accumulator member is soshaped by providing it with a number of sections of different diameters that it delivers a seismic wave of known amplitude and duration.

AMENDED SHEET

SEISMIC WAVE SIMULATION APPARATUS

This invention relates to seismic wave simulation apparatus more particularly but not exclusively for simulating earthquake phenomena occurring in soil and in a foundation embedded in the soil, which foundation may be for example, part of a building.

Conventionally, simulation of a seismic wave or earthquake in a structure or building is done by means of a pseudo-dynamic test (reaction wall) or by the "shaking" table. In order to simulate seismic waves or earthquakes occurring in soil, explosives are used which tend to be inconvenient since the explosives do not generate waves of known energy content and shape and duration having characteristics of earthquakes. Thus, using such methods to simulate seismic waves or earthquakes does not allow wave propagation laws and effects to be properly established through seismic wave simulation in soil or other structures.

It is an object of the present invention to at least alleviate the aforementioned, or other, problem associated with seismic wave simulation apparatus and method.

According to the present invention there is provided seismic wave simulation apparatus capable of generating a simulated seismic wave in a geological specimen, said apparatus comprising an elastic energy accumulator shaped to deliver a seismic wave of known amplitude and duration to the geological specimen under test, the elastic energy accumulator comprising an impactor member held, in use, adjacent the geological test specimen and supported to resist movement in a direction away from the specimen when the elastic energy accumulator is preloaded in said direction by actuator means, the arrangement being such that, in use, the preload force can be quelled suddenly, for example, by triggering an explosive bolt so that the impactor member is released into impact or energy transfer

with the geological specimen thereby transmitting a seismic wave to the geological specimen.

The actuator means may be any convenient means such as a hydraulic or pneumatic actuator.

Usually, the apparatus will include transducers arranged to measure, in use, the mechanical behaviour across the section of the geological specimen through which a seismic wave is being transmitted.

Preferably, the transducers are in the form of bars or elongate members arranged in a direction parallel to the direction of propagation of the seismic wave. Seismic sensors may also be included extending at an angle or transversely of the direction of propagation of the wave.

Usually, the elastic energy accumulator is shaped to simulate a seismic wave of known characteristics in order that wave propagation laws and effects can be properly established. Accordingly, the shape of the elastic energy accumulator may be chosen according to the principles expounded in the description from the estimation of stress wave values between two long bars with different acoustic impedance.

In one embodiment of the present invention, the elastic energy accumulator includes seven cylindrical sections of different diameter. Preferably, one of those sections nearest the actuator means has the smallest diameter of the sections and, where an explosive bolt is provided as aforementioned, to release the impact energy said explosive bolt is, preferably, provided in this section and preferably is aligned diametrically of said section. Said smallest diameter section may adjoin a large diameter section which is connected to two further sections stepped down in diameter connected in turn to a smaller diameter section (which is larger than the first-mentioned

smallest section adjacent the actuator means). This smaller diameter section may be connected to two larger sections which are stepped up in diameter, the last of these sections being adjacent to the geological specimen in use. The length of the elastic energy accumulator (comprised of said seven sections) and the actuator means may be in the order of 500 metres.

The impactor member may be guided and held adjacent the geological specimen, preferably by said last-mentioned section. A blocking system or fixed support may be provided at the rear of said last-mentioned section surrounding the penultimate section, thereby resisting or preventing movement of the impactor member in said direction on the application of the preload force.

Preferably, in order to obtain measurements regarding local displacements of the soil in the geological specimen, said apparatus may include a thin metallic or conductive sheet fixed to the surface of the geological specimen (for example by cement) and connected up to measuring instrumentation such as a Wheastone bridge, for example, in order to obtain superficial strain measurement. In carrying out the test a building foundation or the like may be embedded in the geological specimen in order to investigate the interaction between the soil and foundation on the application of a simulated seismic wave.

The measuring instrumentation may include accelerometers.

Further according to the present invention there is provided a method of inducing or generating a simulated seismic wave in a test specimen, for example, a geological specimen, said method including shaping an elastic energy accumulator to deliver a seismic wave of known amplitude and duration to the test specimen, holding one end of the elastic energy accumulator adjacent to the specimen and

preloading the elastic energy accumulator in a direction away from the specimen, suddenly quelling the preload force, for example by triggering an explosive bolt in the elastic energy accumulator, thereby releasing the elastic energy accumulator into impact or energy transfer with said specimen and transmitting a simulated seismic wave therethrough, said method comprising collecting data from the specimen and analysing said data collected.

Further advantageous apparatus and method features of the present invention will be evident from the following description and drawings.

An embodiment of seismic wave simulation apparatus for generating a seismic wave in a geological specimen will now be described, by way of example only, with reference to the accompanying simplified diagrammatic drawings in which:

FIGURE 1 shows the seismic wave simulation apparatus adjacent a geological specimen having the foundation of a building embedded therein;

FIGURE 2 shows a simple cylindrical bar pre-loaded to yield a virtually rectangular stress wave, and

FIGURE 3 shows cylindrical bars of two different sections arranged to yield a different stress wave pattern.

FIGURE 1 of the drawings shows schematically seismic wave simulation apparatus 1 positioned to the left of a geological specimen 2 in which is embedded the foundation 3 of a building (not shown). The seismic wave simulation apparatus has an elastic energy accumulator 4 comprising an impactor member which can be preloaded in tension in a direction away from the geological specimen 2 (i.e. in a direction reverse to arrow A) by means of a hydraulic actuator 5. The apparatus 1 includes a blocking or support system which effectively fixes the right hand end of the

we obtain a wave which decreases in function of time.

The amplitude and the shape of the wave generated can be found knowing the impedance and also the length of the bars to obtain the transit time. Using the above formula in a numerical programme it is possible to know the shape of the wave which could be generated in function of the geometry of the energy accumulator.

The geological specimen 2 may be a soil rocks specimen and, in order to measure the mechanical behaviour across the section of the geological specimen, transducer bars 8 are provided in the specimen as shown in FIGURE 1. The transducer bars 8 are instrumented with strain gauges and measurements taken in a generally known manner. Additionally, in order to obtain measurements regarding local displacements of the soil in the geological specimen 2 an electrified metallic thin sheet 9 is fixed firmly to the surface of the soil by a cement and connected up to a measuring instrumentation such as a Wheastone bridge, in the case of resistance strain gauges, in order to obtain superficial strain measurement.

Thus, in the present instance, a simulated seismic wave can be transmitted through the geological specimen 2 and through a building foundation 3, so interaction between the soil and the foundation can be studied and evaluated.

Any other measuring instrumentation may be provided such as the accelerometers 10 and embedded seismic sensor bar 11.

It is believed the seismic wave simulation apparatus 1 can be used to provide a deterministic approach to monitoring and predicting:

(a) earthquakes,
(b) large ground displacements of natural and artificial

CLAIMS

1. Seismic wave simulation apparatus capable of generating a simulated seismic wave in a geological specimen, said apparatus comprising an elastic energy accumulator shaped to deliver a seismic wave of known amplitude and duration to the geological specimen under test, the elastic energy accumulator comprising an impactor member held, in use, adjacent the geological test specimen and supported to resist movement in a direction away from the specimen when the elastic energy accumulator is preloaded in said direction by actuator means, the arrangement being such that, in use, the preload force can be quelled suddenly, for example, by triggering an explosive bolt so that the impactor member is released into impact or energy transfer with the geological specimen thereby transmitting a seismic wave to the geological specimen.

2. Apparatus as claimed in Claim 1 in which the actuator means is a hydraulic or pneumatic actuator.

3. Apparatus as claimed in Claim 1 or Claim 2 having tranducers arranged to measure, in use, the mechanical behaviour across the section of the geological specimen through which a seismic wave is being transmitted.

4. Apparatus as claimed in Claim 3 in which the transducers are in the form of bars or elongate members arranged in a direction parallel to the direction of propagation of the seismic wave.

5. Apparatus as claimed in any one of the preceding claims in which seismic sensors are included extending at an angle or transversely of the direction of propagation of the wave.

6. Apparatus as claimed in any one of the preceding

claims in which the elastic energy accumulator is shaped to simulate a seismic wave of known characteristics.

7. Apparatus as claimed in Claim 6 in which the shape of the elastic energy accumulator is chosen according to the principles expounded in the description from the estimation of stress wave values between two long bars with different acoustic impedance.

8. Apparatus as claimed in any one of the preceding claims in which the elastic energy accumulator includes a plurality of cylindrical sections of different diameter.

9. Apparatus as claimed in Claim 8 having a section nearest the actuator means which is the smallest diameter of the sections.

10. Apparatus as claimed in Claim 9 including an explosive bolt aligned diametrically of said section.

11. Apparatus as claimed in Claim 9 or Claim 10 in which said smallest diameter section may adjoin a large diameter section which is connected to two further sections stepped down in diameter connected in turn to a smaller diameter section (which is larger than the first-mentioned smallest section adjacent the actuator means).

12. Apparatus as claimed in Claim 11 in which the smaller diameter section is connected to two larger sections which are stepped up in diameter, the last of these sections being adjacent to the geological specimen in use.

13. Apparatus as claimed in Claim 12 in which the impactor member is guided and held adjacent the geological specimen, by said last-mentioned section.

14. Apparatus as claimed in Claim 13 in which a blocking system or fixed support is provided at the rear of said

last-mentioned section surrounding the penultimate section, thereby resisting or preventing movement of the impactor member in said direction on the application of the preload force.

15. Apparatus as claimed in any one of Claims 8 to 14 in which the elastic energy accumulator includes seven sections.

16. Apparatus as claimed in any one of the preceding claims in which the combined length of the elastic energy accumulator and the actuator means is in the order of 500 metres.

17. Apparatus as claimed in any one of the preceding claims including a thin metallic or conductive sheet fixed to the surface of the geological specimen (for example by cement) and connected up to measuring instrumentation such as a Wheastone bridge, for example, in order to obtain superficial strain measurement.

18. Apparatus as claimed in any one of the preceding claims in which the measuring instrumentation includes accelerometers.

19. A method of inducing or generating a simulated seismic wave in a test specimen, for example, a geological specimen, said method including shaping an elastic energy accumulator to deliver a seismic wave of known amplitude and duration to the test specimen, holding one end of the elastic energy accumulator adjacent to the specimen and preloading the elastic energy accumulator in a direction away from the specimen, suddenly quelling the preload force, for example by triggering an explosive bolt in the elastic energy accumulator, thereby releasing the elastic energy accumulator into impact or energy transfer with said specimen and transmitting a simulated seismic wave therethrough, said method comprising collecting data from

the specimen and analysing said data collected.

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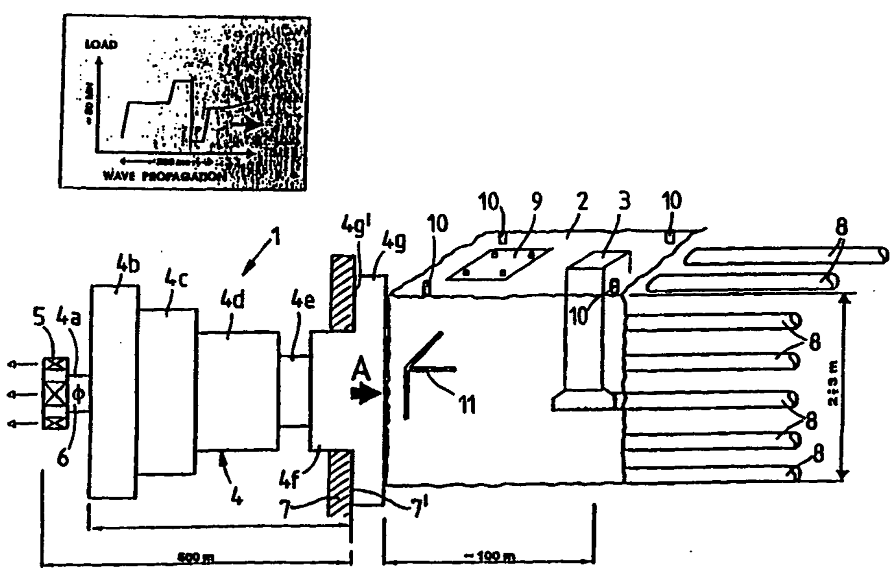

(57) Abstract

Seismic wave simulation apparatus (1) includes an elastic energy accumulator (4) shaped to induce a simulated seismic wave of known form in a geological specimen (2) in which is embedded the foundation (3) of a building. A hydraulic actuator (5) is used to preload the accumulator (4) in a direction reverse to arrow A and an explosive bolt (6) is exploded, thereby releasing the energy of the accumulator (4) as a seismic wave through the geological specimen (2). The specimen (2) is provided with transducer bars (8) and an electrified metallic thin sheet (9) connected to a Wheastone bridge in order to obtain various measurements.

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SEISMIC WAVE SIMULATION APPARATUS

This invention relates to seismic wave simulation apparatus more particularly but not exclusively for simulating earthquake phenomena occurring in soil and in a foundation embedded in the soil, which foundation may be for example, part of a building.

Conventionally, simulation of a seismic wave or earthquake in a structure or building is done by means of a pseudo-dynamic test (reaction wall) or by the "shaking" table. In order to simulate seismic waves or earthquakes occurring in soil, explosives are used which tend to be inconvenient since the explosives do not generate waves of known energy content and shape and duration having characteristics of earthquakes. Thus, using such methods to simulate seismic waves or earthquakes does not allow wave propagation laws and effects to be properly established through seismic wave simulation in soil or other structures.

It is an object of the present invention to at least alleviate the aforementioned, or other, problem associated with seismic wave simulation apparatus and method.

According to the present invention there is provided seismic wave simulation apparatus capable of generating a simulated seismic wave in a geological specimen, said apparatus comprising an elastic energy accumulator shaped to deliver a seismic wave of known amplitude and duration to the geological specimen under test, the elastic energy accumulator comprising an impactor member held, in use, adjacent the geological test specimen and supported to resist movement in a direction away from the specimen when the elastic energy accumulator is preloaded in said direction by actuator means, the arrangement being such that, in use, the preload force can be quelled suddenly, for example, by triggering an explosive bolt so that the impactor member is released into impact or energy transfer

with the geological specimen thereby transmitting a seismic wave to the geological specimen.

The actuator means may be any convenient means such as a hydraulic or pneumatic actuator.

Usually, the apparatus will include transducers arranged to measure, in use, the mechanical behaviour across the section of the geological specimen through which a seismic wave is being transmitted.

Preferably, the transducers are in the form of bars or elongate members arranged in a direction parallel to the direction of propagation of the seismic wave. Seismic sensors may also be included extending at an angle or transversely of the direction of propagation of the wave.

Usually, the elastic energy accumulator is shaped to simulate a seismic wave of known characteristics in order that wave propagation laws and effects can be properly established. Accordingly, the shape of the elastic energy accumulator may be chosen according to the principles expounded in the description from the estimation of stress wave values between two long bars with different acoustic impedance.

In one embodiment of the present invention, the elastic energy accumulator includes seven cylindrical sections of different diameter. Preferably, one of those sections nearest the actuator means has the smallest diameter of the sections and, where an explosive bolt is provided as aforementioned, to release the impact energy said explosive bolt is, preferably, provided in this section and preferably is aligned diametrically of said section. Said smallest diameter section may adjoin a large diameter section which is connected to two further sections stepped down in diameter connected in turn to a smaller diameter section (which is larger than the first-mentioned

smallest section adjacent the actuator means). This smaller diameter section may be connected to two larger sections which are stepped up in diameter, the last of these sections being adjacent to the geological specimen in use. The length of the elastic energy accumulator (comprised of said seven sections) and the actuator means may be in the order of 500 metres.

The impactor member may be guided and held adjacent the geological specimen, preferably by said last-mentioned section. A blocking system or fixed support may be provided at the rear of said last-mentioned section surrounding the penultimate section, thereby resisting or preventing movement of the impactor member in said direction on the application of the preload force.

Preferably, in order to obtain measurements regarding local displacements of the soil in the geological specimen, said apparatus may include a thin metallic or conductive sheet fixed to the surface of the geological specimen (for example by cement) and connected up to measuring instrumentation such as a Wheastone bridge, for example, in order to obtain superficial strain measurement. In carrying out the test a building foundation or the like may be embedded in the geological specimen in order to investigate the interaction between the soil and foundation on the application of a simulated seismic wave.

The measuring instrumentation may include accelerometers.

Further according to the present invention there is provided a method of inducing or generating a simulated seismic wave in a test specimen, for example, a geological specimen, said method including shaping an elastic energy accumulator to deliver a seismic wave of known amplitude and duration to the test specimen, holding one end of the elastic energy accumulator adjacent to the specimen and

preloading the elastic energy accumulator in a direction away from the specimen, suddenly quelling the preload force, for example by triggering an explosive bolt in the elastic energy accumulator, thereby releasing the elastic energy accumulator into impact or energy transfer with said specimen and transmitting a simulated seismic wave therethrough, said method comprising collecting data from the specimen and analysing said data collected.

Further advantageous apparatus and method features of the present invention will be evident from the following description and drawings.

An embodiment of seismic wave simulation apparatus for generating a seismic wave in a geological specimen will now be described, by way of example only, with reference to the accompanying simplified diagrammatic drawings in which:

FIGURE 1 shows the seismic wave simulation apparatus adjacent a geological specimen having the foundation of a building embedded therein;

FIGURE 2 shows a simple cylindrical bar pre-loaded to yield a virtually rectangular stress wave, and

FIGURE 3 shows cylindrical bars of two different sections arranged to yield a different stress wave pattern.

FIGURE 1 of the drawings shows schematically seismic wave simulation apparatus 1 positioned to the left of a geological specimen 2 in which is embedded the foundation 3 of a building (not shown). The seismic wave simulation apparatus has an elastic energy accumulator 4 comprising an impactor member which can be preloaded in tension in a direction away from the geological specimen 2 (i.e. in a direction reverse to arrow A) by means of a hydraulic actuator 5. The apparatus 1 includes a blocking or support system which effectively fixes the right hand end of the

elastic energy accumulator 4 whilst said accumulator is preloaded in tension.

The elastic energy accumulator is specially shaped to simulate a seismic wave of known characteristics, such as the wave shown in the top left hand corner of FIGURE 1 in order that wave propagation laws and effects throughout the geological specimen 2 and foundation 3 can be properly established.

It is to be noted that the energy accumulator in the present instance includes seven sections 4a to 4g of varying diameter and the geometry of this energy accumulator may be modified in order to obtain different wave shapes of known characteristics.

FIGURE 1 shows only one such configuration where reflections can provide many wave shapes of different amplitude in tension and in compression. Section 4a of the energy accumulator 4 has the narrowest diameter and an explosive bolt 6 extends diametrically of the section.

It is to be understood that once the energy accumulator has been preloaded by the hydraulic actuator this energy can be released and transmitted as a seismic wave through the geological specimen 2 when the bolt 6 is exploded. In order to create wave propagation the energy stored in the energy accumulator 4 should be released suddenly. The explosive bolt 6 is the weak part of the energy accumulator and when this part is broken the energy is released. Usually, explosive will be inserted inside the bolt which allows said bolt to rupture in a very brief time in order to obtain a stress wave with a short rise time.

The right hand end section 4g of the energy accumulator has a rear face 4g' which engages the front face 7' of the blocking or support system 7 when the

hydraulic actuator 5 places the energy accumulator 4 under preload conditions, in a manner which should be evident from the drawings.

The manner in which the geometry of the energy accumulator 4 may be modified in order to obtain particular wave shapes is explained below. The duration of the wave is a function of the length of the energy accumulator and the amplitude can be determined by modifying the acoustic impedance along the energy accumulator 4.

Estimation of the stress wave values between two long bars with different acoustic impedance.

It can be shown that the amplitude of the stress σ in the case of stress wave propagation is a linear function of the particle velocity V:

$$\sigma = \rho . C . V. \qquad (1)$$

ρ is the density of the medium (bar)

C is the wave velocity.

This equation can be used to estimate the wave transmission and reflection through the interfaces of two bars in contact with a different acoustical impedance. In this case two conditions should be satisfied:

The loads at the interface between the two bars are equal at each instant:

$$A(\sigma_i + \sigma_r) = A.\ \sigma_t \qquad (2)$$

A is the cross sectional area of the bar at the interface.

The particle velocities at the interface between the two bars are equal at each instant:

$$V_i = V_r + V_t \qquad (3)$$

By using equation (1) in equation (2) we obtain that:

$$A_1 (\rho_1 C_1 V_i) + A_1(\rho_1 C_1 V_r) = A_2 (\rho_2 C_2 V_t) \qquad (4)$$

with equation 3 we obtain that:

$$V_r = \frac{A_{2r}\rho_2 C_2 - A_1\rho_1 C_1}{A_{2r}\rho_2 C_2 + A_1\rho_1 C_1} V_1 \qquad (5)$$

and

$$V_t = \frac{2A_1\rho_1 C_2}{A_{2r}\rho_2 C_2 + A_1\rho_1 C_1} V_i \qquad (6)$$

By writing these equations for stresses we have:

$$\sigma_2 = \frac{A_{2r}\rho_2 C_2 - A_1\rho_1 C_1}{A_{2r}\rho_2 C_2 + A_1\rho_1 C_1} \sigma_i \qquad (7)$$

$$\sigma_t = \frac{2A_1\rho_2 C_2}{A_{2r}\rho_2 C_2 + A_1\rho_1 C_1} \sigma_1 \qquad (8)$$

If a bar is preloaded with an acoustic impedance $\rho_1 A_1 C_1$ the stress wave generated is nearly rectangular (FIGURE 2). This application could be the starting point to understand the basic behaviour of wave propagation in the soil and will permit the validation of the calcul codes used to describe the earthquake phenomena.

Two cylindrical bars with two different sections (as shown in FIGURE 3) and a longitudinal stress wave which propagates from one end of the left bar can now be considered. If the acoustic impedance $\rho 1 C_1 A_1 > \rho_2 A_2 C_2$ then

we obtain a wave which decreases in function of time.

The amplitude and the shape of the wave generated can be found knowing the impedance and also the length of the bars to obtain the transit time. Using the above formula in a numerical programme it is possible to know the shape of the wave which could be generated in function of the geometry of the energy accumulator.

The geological specimen 2 may be a soil rocks specimen and, in order to measure the mechanical behaviour across the section of the geological specimen, transducer bars 8 are provided in the specimen as shown in FIGURE 1. The transducer bars 8 are instrumented with strain gauges and measurements taken in a generally known manner. Additionally, in order to obtain measurements regarding local displacements of the soil in the geological specimen 2 an electrified metallic thin sheet 9 is fixed firmly to the surface of the soil by a cement and connected up to a measuring instrumentation such as a Wheastone bridge, in the case of resistance strain gauges, in order to obtain superficial strain measurement.

Thus, in the present instance, a simulated seismic wave can be transmitted through the geological specimen 2 and through a building foundation 3, so interaction between the soil and the foundation can be studied and evaluated.

Any other measuring instrumentation may be provided such as the accelerometers 10 and embedded seismic sensor bar 11.

It is believed the seismic wave simulation apparatus 1 can be used to provide a deterministic approach to monitoring and predicting:

(a) earthquakes,
(b) large ground displacements of natural and artificial

origin;

(c) explosion effects of mining work and large civil engineering works,

(d) volcanic activity,

(e) the dynamic interaction between soil and structures.

This approach is based on the stress wave release and wave propagation measurements from or in fracturing rock specimens.

Furthermore, the seismic wave simulation wave apparatus allows different kinds of soils to be submitted to earthquake-like effects at large-scale, the interaction between soil and foundations to be studied. The apparatus should allow precise measures of attenuation laws for acceleration, magnitude as a function of distance etc. since initial energy into the soil is well known and the measurement is performed without modification of the wave. Propagation laws and explosive waves for the optimisation of mining and large excavation works could be tested and a large displacement could be reached (up to 5 metres) for an ELEA of 500 meters.

Advantageously, embodiments of the present invention may provide:

(1) A precision seismic load testing device of large geological specimens of homogeneous or composite nature reproducing a significantive sample of the earth crust in which propagation parameters (load, displacement, speed, accelerations) of seismic/explosive waves can be locally and globally measured.

(2) Accumulation of a large amount of potential energy released as a real seismic/explosive wave of well known shape, amplitude and duration by proper sizing of length and cross section of the ELEA allowing very large displacements without enormous complication of

inertial effects that would characterise, for example, a hydraulic machine.

(3) Bar transducers having a tuned mechanical impedance with the soil/rock specimen in order to capture without modification the seismic/explosive wave arising in the points of application.

(4) Bar transducers utilised as geotechnical transducers having the unique characteristic of the local contemporaneous direct measurement of load, displacement, speed and accelerations provoked by the seismic/explosive wave propagation because of their elasticity and length.

It is to be understood that the scope of the present invention is not to be unduly limited by a particular choice of terminology and that a specific term may be replaced by any equivalent or generic term. Further it is to be understood that individual features, method or functions relating to the seismic wave simulation wave apparatus might be individually patentably inventive. The singular may include the plural and vice versa. Additionally, any range mentioned herein for any variable or parameter shall be taken to include a disclosure of any derivable subrange within that range or any particular value of the variable or parameter range within, or at an end of, the range or subrange.

CLAIMS

1. Seismic wave simulation apparatus capable of generating a simulated seismic wave in a geological specimen, said apparatus comprising an elastic energy accumulator shaped to deliver a seismic wave of known amplitude and duration to the geological specimen under test, the elastic energy accumulator comprising an impactor member held, in use, adjacent the geological test specimen and supported to resist movement in a direction away from the specimen when the elastic energy accumulator is preloaded in said direction by actuator means, the arrangement being such that, in use, the preload force can be quelled suddenly, for example, by triggering an explosive bolt so that the impactor member is released into impact or energy transfer with the geological specimen thereby transmitting a seismic wave to the geological specimen.

2. Apparatus as claimed in Claim 1 in which the actuator means is a hydraulic or pneumatic actuator.

3. Apparatus as claimed in Claim 1 or Claim 2 having tranducers arranged to measure, in use, the mechanical behaviour across the section of the geological specimen through which a seismic wave is being transmitted.

4. Apparatus as claimed in Claim 3 in which the transducers are in the form of bars or elongate members arranged in a direction parallel to the direction of propagation of the seismic wave.

5. Apparatus as claimed in any one of the preceding claims in which seismic sensors are included extending at an angle or transversely of the direction of propagation of the wave.

6. Apparatus as claimed in any one of the preceding

claims in which the elastic energy accumulator is shaped to simulate a seismic wave of known characteristics.

7. Apparatus as claimed in Claim 6 in which the shape of the elastic energy accumulator is chosen according to the principles expounded in the description from the estimation of stress wave values between two long bars with different acoustic impedance.

8. Apparatus as claimed in any one of the preceding claims in which the elastic energy accumulator includes a plurality of cylindrical sections of different diameter.

9. Apparatus as claimed in Claim 8 having a section nearest the actuator means which is the smallest diameter of the sections.

10. Apparatus as claimed in Claim 9 including an explosive bolt aligned diametrically of said section.

11. Apparatus as claimed in Claim 9 or Claim 10 in which said smallest diameter section may adjoin a large diameter section which is connected to two further sections stepped down in diameter connected in turn to a smaller diameter section (which is larger than the first-mentioned smallest section adjacent the actuator means).

12. Apparatus as claimed in Claim 11 in which the smaller diameter section is connected to two larger sections which are stepped up in diameter, the last of these sections being adjacent to the geological specimen in use.

13. Apparatus as claimed in Claim 12 in which the impactor member is guided and held adjacent the geological specimen, by said last-mentioned section.

14. Apparatus as claimed in Claim 13 in which a blocking system or fixed support is provided at the rear of said

last-mentioned section surrounding the penultimate section, thereby resisting or preventing movement of the impactor member in said direction on the application of the preload force.

15. Apparatus as claimed in any one of Claims 8 to 14 in which the elastic energy accumulator includes seven sections.

16. Apparatus as claimed in any one of the preceding claims in which the combined length of the elastic energy accumulator and the actuator means is in the order of 500 metres.

17. Apparatus as claimed in any one of the preceding claims including a thin metallic or conductive sheet fixed to the surface of the geological specimen (for example by cement) and connected up to measuring instrumentation such as a Wheastone bridge, for example, in order to obtain superficial strain measurement.

18. Apparatus as claimed in any one of the preceding claims in which the measuring instrumentation includes accelerometers.

19. A method of inducing or generating a simulated seismic wave in a test specimen, for example, a geological specimen, said method including shaping an elastic energy accumulator to deliver a seismic wave of known amplitude and duration to the test specimen, holding one end of the elastic energy accumulator adjacent to the specimen and preloading the elastic energy accumulator in a direction away from the specimen, suddenly quelling the preload force, for example by triggering an explosive bolt in the elastic energy accumulator, thereby releasing the elastic energy accumulator into impact or energy transfer with said specimen and transmitting a simulated seismic wave therethrough, said method comprising collecting data from

the specimen and analysing said data collected.

1 / 2

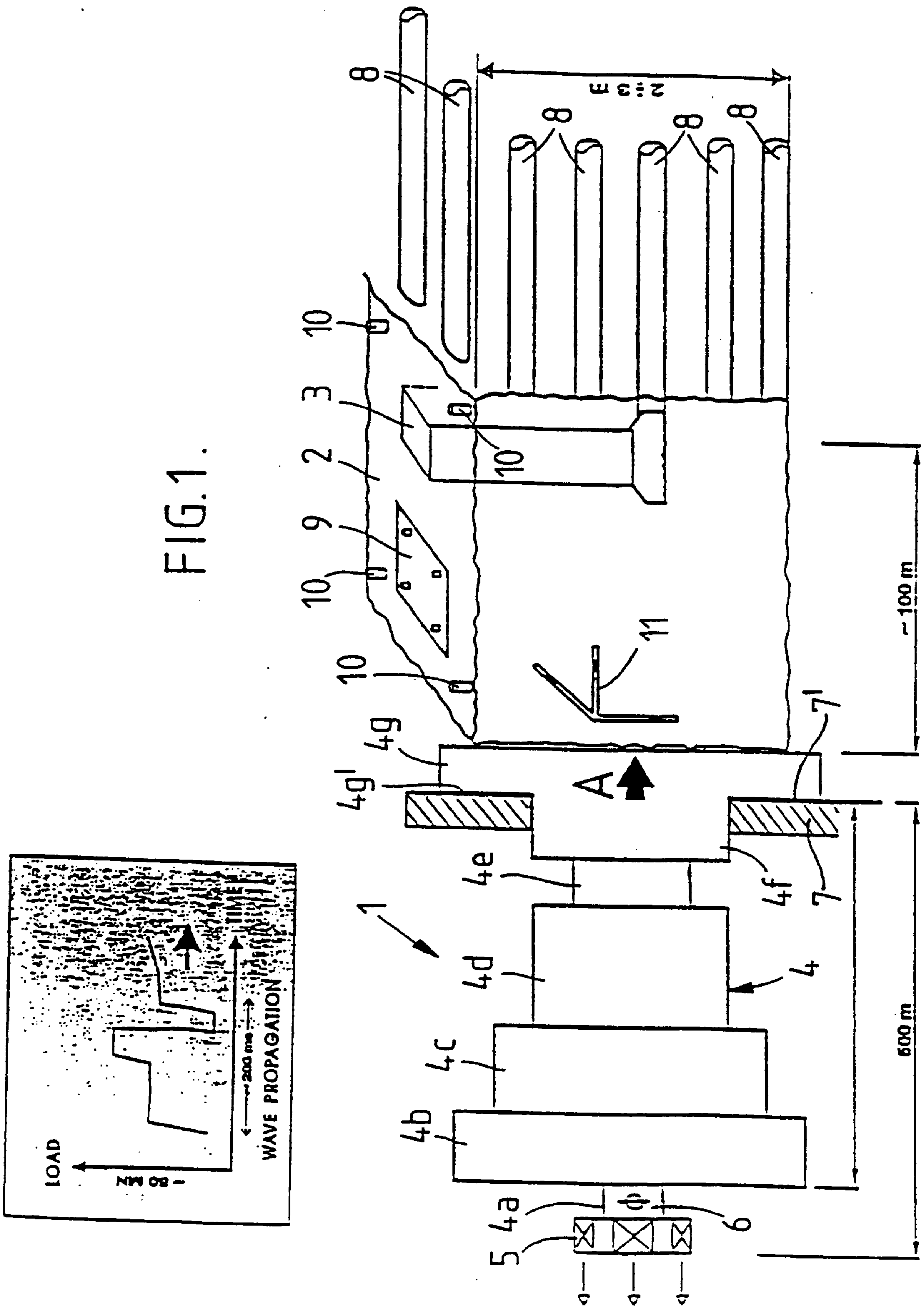

8
2÷3 m
10
3
2
9
11
~100 m
4g
4g'
A
7'
4e
4f
7
1
4d
4
4c
4b
500 m
4a
6
5
LOAD
~80 MN
200 ms
TIME
WAVE PROPAGATION

FIG.1.

FIG. 2.

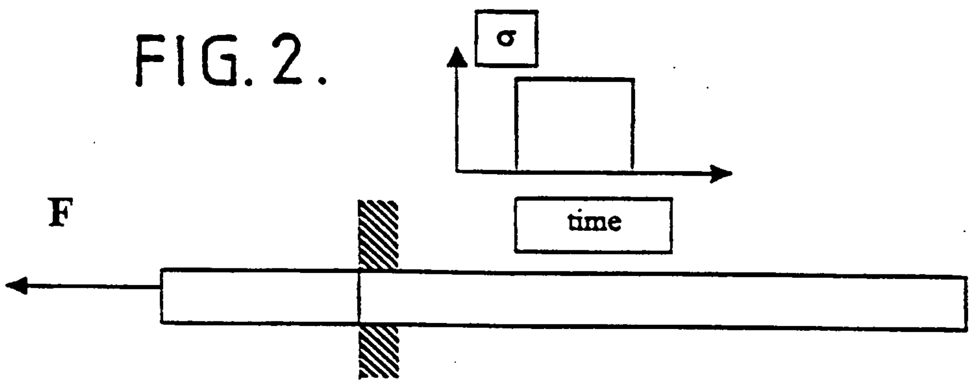
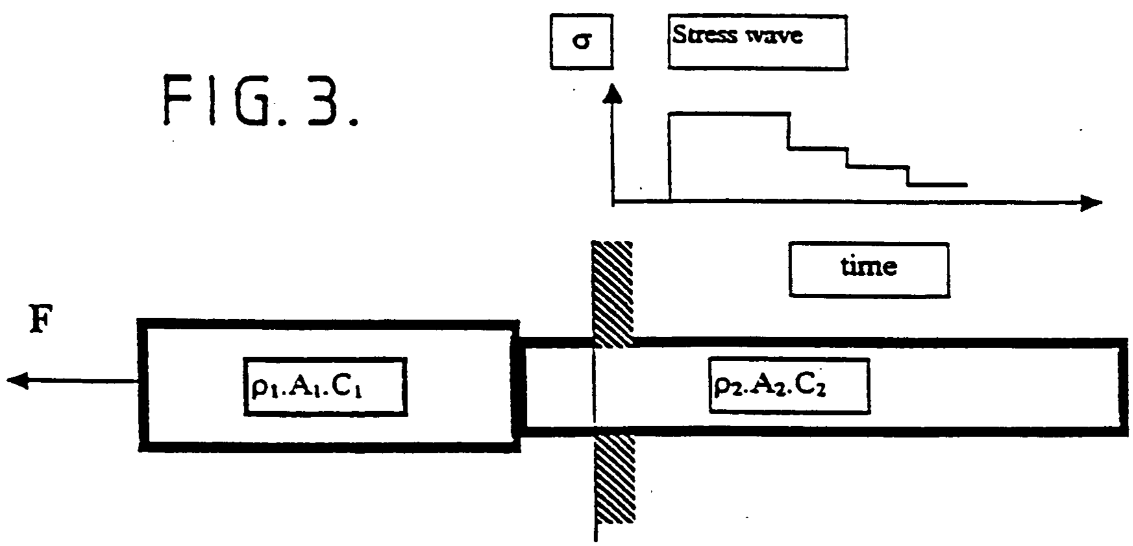


FIG. 3.



INTERNATIONAL SEARCH REPORT

Int. .ational Application No
PCT/EP 97/05417

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01V1/145 G01M7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01V G01M G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 007 740 A (EURATOM) 6 February 1980 see abstract see page 1, line 18 - line 21 see page 2, line 19 - page 3, line 19 see page 4, line 2 - line 24 see page 5, line 11 - line 26 see claims 1-4; figures 1,2 ---	1-4,19
A	GB 2 211 611 A (COAL IND) 5 July 1989 see abstract; figure 1 ---	1-4,19
A	FR 2 229 967 A (EURATOM) 13 December 1974 see claims 1,2,4 ---	1-4
A	EP 0 410 370 A (EUROP COMMUNITIES) 30 January 1991 see column 1, line 12 - line 26 --- -/--	4

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
29 January 1998	12/02/1998
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer de Heering, Ph.

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INTERNATIONAL SEARCH REPORT

Int. ...tional Application No
PCT/EP 97/05417

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 81 00459 A (CONOCO INC;FAIR D; BULLER P) 19 February 1981 ---	
A	DI PRISO M ET AL: "PVDF PIEZOELECTRIC SENSORS AND RELATED ELECTRONICS STRUCTURAL ENGINEERING APPLICATIONS" PROCEEDINGS OF THE INSTRUMENTATION AND MEASUREMENT TECHNOLOGY CONFERENCE, ORVINE, CA., MAY 18 - 20, 1993, no. -, 18 May 1993, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 228-231, XP000400175 see figure 1 ---	4,17
P,A	PATENT ABSTRACTS OF JAPAN vol. 097, no. 006, 30 June 1997 & JP 09 043093 A (ONO SOKKI CO LTD), 14 February 1997, see abstract -----	5

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 97/05417

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0007740 A	06-02-80	CA 1134170 A	26-10-82
		JP 55033692 A	08-03-80
GB 2211611 A	05-07-89	NONE	
FR 2229967 A	13-12-74	BE 815038 A	02-09-74
		DE 2422872 A	05-12-74
		GB 1473863 A	18-05-77
		LU 70110 A	17-10-74
		NL 7406580 A	19-11-74
EP 0410370 A	30-01-91	LU 87562 A	18-02-91
WO 8100459 A	19-02-81	AT 9613 T	15-10-84
		AU 518722 B	15-10-81
		AU 6093380 A	19-02-81
		CA 1162634 A	21-02-84
		DD 152631 A	02-12-81
		DK 526580 A	14-04-81
		EP 0024116 A	25-02-81
		EP 0034585 A	02-09-81
		US 4492285 A	08-01-85
		ZA 8004915 A	26-08-81